Report No. IITRI-A6155-3

COMPOSITIONAL ANALYSIS OF LUNAR AND PLANETARY SURFACES USING NEUTRON CAPTURE GAMMA RAYS

for

Dr. Martin J. Swetnick
Code SL
National Aeronautics and Space Administration
Washington, D. C. 20546

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November 1, 1966 through February 15, 1967

Prepared by

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FOREWORD

This is Report No. IITRI-A6155-3 under Contract No. NASr 65(18), entitled "Compositional Analysis of Lunar and Planetary Surfaces Using Neutron Capture Gamma Rays," covering the period from November 1, 1966 to February 15, 1967.

The following personnel have contributed to the work described in this report: J. H. Reed, principal investigator and J. W. Mandler.

Respectfully submitted,

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ABSTRACT

COMPOSITIONAL ANALYSIS OF LUNAR AND PLANETARY SURFACES USING NEUTRON CAPTURE GAMMA RAYS

The objective of this research program is to establish the practicality of using neutron capture gamma rays as a part of NASA's combined neutron experiment for lunar and planetary surface analysis. This requires (1) the determination of the sensitivity of the technique under reasonable field conditions with the experimental configuration optimized for the capture gamma-ray technique and (2) the determination of the effects which integration with other neutron techniques will have on its sensitivity.

This report summarizes work done during this period November 1, 1966 to February 15, 1967.

Capture gamma-ray spectra were studied from a large sample using a pulsed 14 MeV neutron source under a variety of experimental conditions. It has been determined that horizontal detection geometry yields better sensitivity than does vertical geometry and that a moderating material above the neutron source (about 4 to 8 cm thick) greatly increases the sensitivity of the capture gamma-ray technique. Details of this work were presented at a NASA coordinated meeting held at Sandia Corporation February 7-8, 1967.

I. INTRODUCTION

During this reporting period considerable progress was made in establishing the technique using thermal neutron capture gamma rays induced by 14 MeV neutrons as a practical analytical method for consideration in NASA's combined neutron experiment for lunar and planetary surface analysis. Capture gamma-ray spectra were studied from a large (approximating semi-infinite) sample using a pulsed 14 MeV neutron source under a variety of experimental conditions to determine the effect of detection geometry and neutron moderator thickness. The effect of two thermal neutron shields and several configurations of fast neutron shadow shields has also been experimentally studied.

A meeting of NASA and the contractors that are participating in the combined neutron experiment was held at Sandia Corporation February 7 and 8 to determine the status of each of the experimental studies. Details of the experimentation conducted during this reporting period were presented at the meeting and will, therefore, only be summarized in this report.

II. NEUTRON SHIELDING FOR THE DETECTOR

Since for the capture gamma-ray experiment the gamma-ray spectrum is obtained between neutron pulses, the primary result of neutron interaction with the NaI(Tl) detector that is of concern is the neutron activation of the crystal through the $I^{127}(n,\gamma)I^{128}$ reaction. A series of experiments was performed to determine the degree to which the activation could be reduced by (1) the use of thermal neutron shielding in the vicinity of the detector and (2) the addition of a fast neutron shadow shield between the detector and the neutron source. The results are summarized in Table 1. For comparison the activation produced in an unshielded crystal is defined as 100 arbitrary units. The addition of a thermal neutron shield around the detector reduced the activation by about 25% - the boral (0.254 gm/cm^{2}B) and Li^6F (0.047 gm/cm^2 Li^6) giving nearly identical results. The addition of a shadow shield, e.g. 6" copper or 12" carbon, reduced the activation by an additional 20%.

The copper and carbon shadow shields were designed to shield the detector from neutrons emitted from the tritium target only. However, when a moderator is placed above the target, a new source of neutrons is created. Comparison of the last two entries in Table 1 indicates that if a moderator is used, the shadow shield should be shaped to provide shielding between the moderator and the detector.

While a shadow shield is helpful to some extent, the material used for this shield is not critical to the capture gamma-ray experiment. For the thermal neutron shield lithium-6 is preferred over boron because of the 477 keV gamma ray associated with neutron capture in boron-10.

Table 1

EFFECT OF NEUTRON SHIELDING ON CRYSTAL ACTIVATION

Shield Configurations	Relative Crystal Activation
Bare crystal - No paraffin - No shadow shield	100
Boral - No Pb - No paraffin - No shadow shield	77
Li^6F - No Pb - No paraffin - No shadow shield	72
Boral - No Pb - No paraffin - 6" carbon shadow shield	61
Boral - No Pb - No paraffin - 12" copper shadow shield	60
Boral - No Pb - No paraffin - 6" copper shadow shield	57
Boral - No Pb - No paraffin - 12" carbon shadow shield	53
Boral - No Pb - 8 cm paraffin - 12" carbon shadow shield	66

III. CAPTURE-GAMMA-RAY MEASUREMENTS

The capture gamma-ray spectrum from the iron-sand model has been observed under a variety of experimental conditions. A study of these spectra results in a preliminary understanding of the effects which detector-source geometry and the presence of moderating material have on the observed spectrum.

Table 2 summarizes the effects which various thicknesses of paraffin above the neutron source have on the observed gamma-ray spectrum. The term "Relative Spectral Quality", used in Table 2, is defined as the ratio of the counts recorded in the energy range 7.0 to 7.7 MeV ($Fe(n,\gamma)$) to the counts recorded in the energy range 5.3 to 5.7 MeV ($O(n,p) + Fe(n,\gamma)$). If the ratio is as small as 0.3, as with no moderating material, the gamma rays from the O(n,p) reaction dominate the spectrum while if the ratio is as large as 0.6, as with 8 cm of paraffin, the iron capture gamma rays dominate. The presence of the moderating material was also found to increase the absolute intensity of the capture gamma rays. Hence, the use of a moderating material above the neutron source is very desirable in connection with the capture gamma-ray experiment.

The introduction of a moderating material between the neutron source and the sample has also been studied. Paraffin in this position did not significantly increase either the "Relative Spectral Quality" ratio or the absolute capture gamma-ray intensity. This configuration has been disregarded in subsequent studies.

Table 2

THE EFFECT OF MODERATOR THICKNESS
(ABOVE THE NEUTRON SOURCE)
ON SPECTRAL RESPONSE

cm of Paraffin	Relative Spectral Quality	Relative Intensity Fe(n,γ)
0	0.31	32
2	0.40	49
4	0.46	71
6	0.58	87
8	0.61	120

(No moderator between target and sample.)

Table 3

THE EFFECT OF DETECTOR POSITION
ON SPECTRAL RESPONSE (IRON-SAND-2 SAMPLE)

Source to Crystal Distance	Geometry	Spectral Quality Index	Relative Intensity Fe(n,γ)
37 cm	Horizontal	0.31	106
52 cm	Horizontal	0.21	73
37 cm	Vertical	0.14	66
52 cm	Vertical	0.08	36

Table 3 summarizes the effect detector position has on the observed gamma-ray spectrum. A second iron-sand model containing considerably less iron was used in these measurements. The term "Spectral Quality Index" used in Table 3 is defined as the ratio of the iron capture gamma-ray counts recorded in the energy range 7.0 to 7.6 MeV to the counts recorded in the energy range 5.3 to 5.7 MeV due to the gamma rays from the O(n,p) reaction. The results indicate that horizontal detector-source geometry is to be preferred over vertical and that the shorter distance between the source and the crystal yields the better results.

Spectrum A in Figure 1 indicates the quality of spectrum that can be obtained, at present, with a 3" x 3" NaI(Tl) detector. The legend in Figure 1 describes the conditions under which gamma-ray spectrum was obtained. For reasons of neutron economy the neutron source was placed as close as possible to the surface of the sample (5 cm). Each neutron pulse contained approximately 3×10^3 neutrons and a total neutron yield of 1.1×10^{10} was required for the acquisition of spectrum A. Note the presence of capture gamma rays from the iron and silicon at 7.64, 7.10, 6.60, 5.00, 4.42, 3.92, 3.50, and 2.73 MeV. The capture gamma ray at 2.23 MeV from hydrogen is due to neutron capture in the hydrogenous moderator.

Spectrum B in Figure 1 was obtained under the same conditions as Spectrum A with the exception of timing. Spectrum A corresponds to the gamma-ray spectrum that is present during the time interval 250-450 μsec after the neutron pulse while

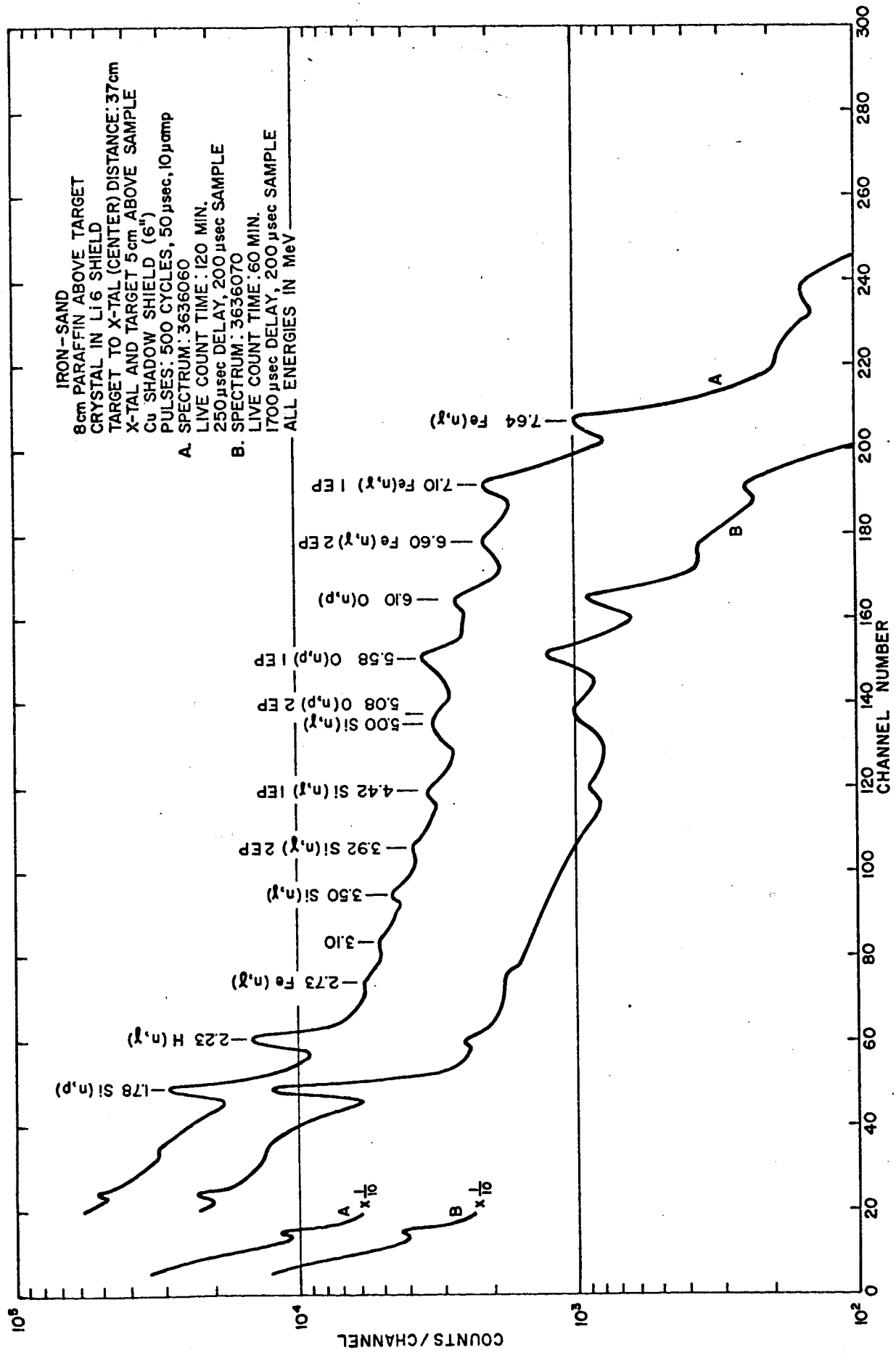
IRON-SAND
8cm PARAFFIN ABOVE TARGET
CRYSTAL IN Li6 SHIELD
TARGET TO X-TAL (CENTER) DISTANCE: 37cm
X-TAL AND TARGET 5cm ABOVE SAMPLE
Cu SHADOW SHIELD (6")
PULSES: 500 CYCLES, 50 μsec, 10 μamp
A. SPECTRUM: 3636060
LIVE COUNT TIME: 120 MIN.
250 μsec DELAY, 200 μsec SAMPLE
B. SPECTRUM: 3636070
LIVE COUNT TIME: 60 MIN.
1700 μsec DELAY, 200 μsec SAMPLE
ALL ENERGIES IN MeV
7.64 Fe(n,γ)
7.10 Fe(n,γ) 1 EP
6.60 Fe(n,γ) 2 EP
6.10 O(n,p)
5.58 O(n,p) 1 EP
5.08 O(n,p) 2 EP
5.00 Si(n,γ)
4.42 Si(n,γ) 1 EP
3.92 Si(n,γ) 2 EP
3.50 Si(n,γ)
3.10
2.73 Fe(n,γ)
2.23 H(n,γ)
1.78 Si(n,p)
A
B
COUNTS / CHANNEL
CHANNEL NUMBER

FIGURE 1

Spectrum B corresponds to the spectrum that is present during the time interval 1700-1900 μsec after the neutron pulse. Note that the iron and silicon capture gamma rays are gone in Spectrum B, (since the thermal neutrons in the iron-sand model exhibit a life time of about 280 μsec), leaving the oxygen and silicon activation lines. In both spectra the sharp increase in count rate below 2 MeV is due to the neutron activation of the detector. Spectrum B can be considered the background that is present in Spectrum A. The background corrected capture gamma-ray spectrum (Spectrum A minus Spectrum B) is shown in Figure 2.

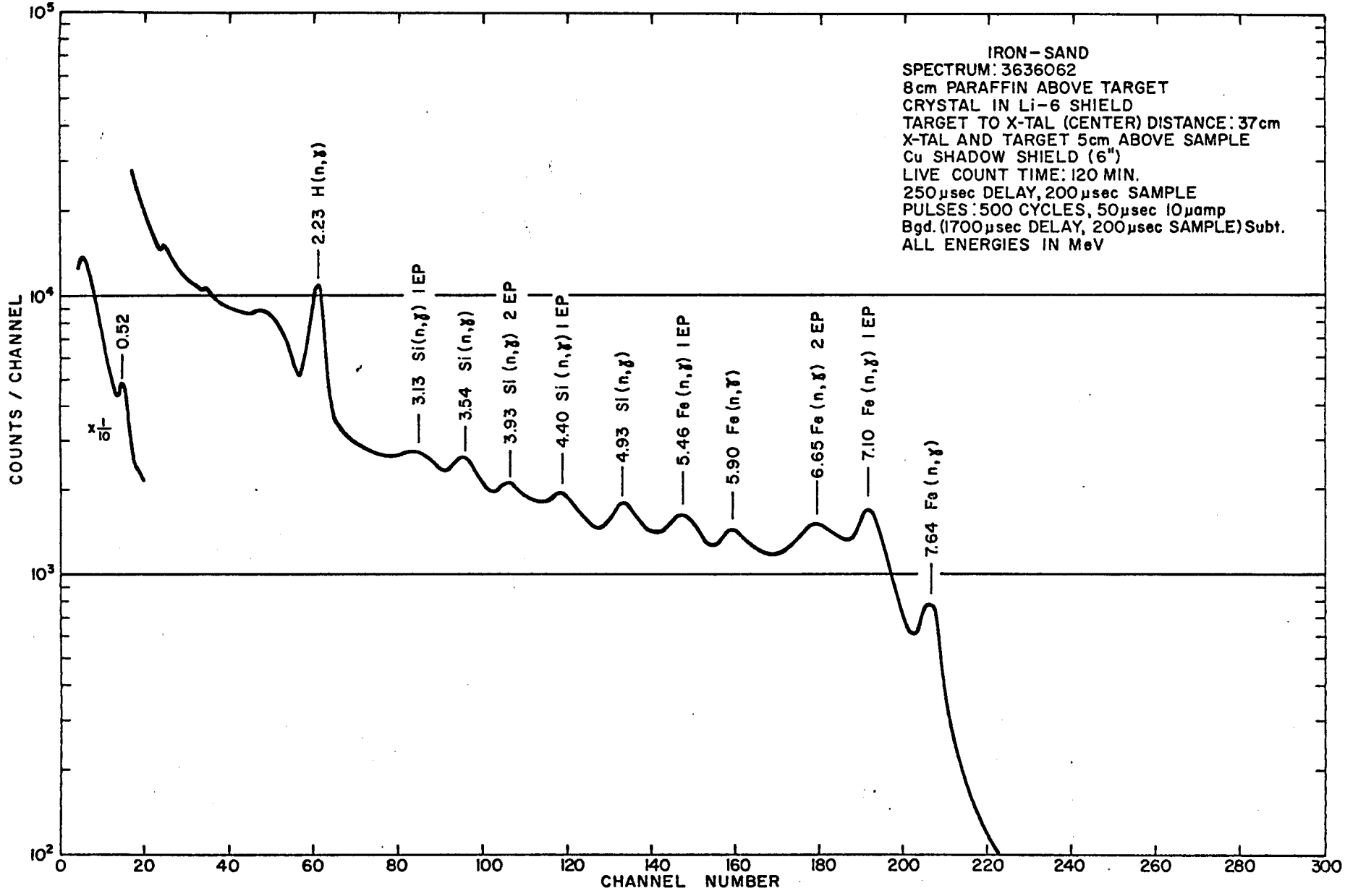
IRON-SAND
SPECTRUM: 3636062
8cm PARAFFIN ABOVE TARGET
CRYSTAL IN Li-6 SHIELD
TARGET TO X-TAL (CENTER) DISTANCE: 37cm
X-TAL AND TARGET 5cm ABOVE SAMPLE
Cu SHADOW SHIELD (6")
LIVE COUNT TIME: 120 MIN.
250μsec DELAY, 200μsec SAMPLE
PULSES: 500 CYCLES, 50μsec 10μamp
Bgd. (1700μsec DELAY, 200μsec SAMPLE) Subt.
ALL ENERGIES IN MeV
COUNTS / CHANNEL
CHANNEL NUMBER
0.52
2.23 H(n,γ)
3.13 Si(n,γ) 1 EP
3.54 Si(n,γ)
3.93 Si (n,γ) 2 EP
4.40 Si (n,γ) 1 EP
4.93 Si(n,γ)
5.46 Fe (n,γ) 1 EP
5.90 Fe (n,γ)
6.65 Fe (n,γ) 2 EP
7.10 Fe (n,γ) 1 EP
7.64 Fe (n,γ)

FIGURE 2

IV. FUTURE WORK

At the Sandia Meeting of February 7-8 it was agreed that three areas needed immediate attention:

1. A moderating material above the neutron source, while very beneficial to the capture gamma-ray experiment, is apparently detrimental to the neutron die-away experiment. It was agreed that Socony Mobil Oil Co. and IITRI would work closely together and hopefully arrive at an agreeable solution to this dilemma. This study will include, for example, investigating the effect of adding a neutron absorber to the moderating material thus preventing thermal neutrons from leaking out of the moderator for extended periods of time after the neutron pulse.
2. An overloading of the detector system has been observed immediately after a neutron pulse. At present this overload condition requires 200-300 μsec for recovery. This troublesome effect will be investigated to determine its origin so that if possible it may be minimized.
3. Questions were raised as to the technique and accuracy of the neutron measurements in regard to the total number of neutrons required per measurement and the number of neutrons generated per pulse. Additional neutron data will be obtained so that the results IITRI reported at the Sandia Meeting can be verified. The results of this investigation complimented by the study regarding the

overloading (above) will allow IITRI to be more specific in the specifications that can be given Sandia Corporation in the procurement of the neutron generator.

The remainder of the present contract will be devoted to the investigation of these areas.